

Wildfire Smoke

A Guide for Public Health Officials



July 2001

Introduction

Smoke rolls into town, blanketing the city, turning on street lights, creating an eerie and choking fog. Switch boards light up as people look for answers. Citizens want to know what they should do to protect themselves. Schools want to know if practices should be cancelled. The media wants to know how dangerous the smoke really is.

Smoke events often catch us off-guard. This guide is intended to provide local public health officials the information they need during a wildfire smoke event so they can adequately communicate health risks and precautions to the public. It is the result of a collaborative effort that brought together scientists, air quality specialists and public health professionals from national, state and local agencies.



Composition of smoke

Smoke is made up primarily of carbon dioxide, water vapor, carbon monoxide, particulate matter, hydrocarbons and other organics, nitrogen oxides and trace minerals. The composition of smoke varies with fuel type: different wood and vegetation are composed of varying amounts of cellulose, lignin, tannins and other polyphenolics, oils, fats, resins, waxes and starches which produce different compounds when burned.

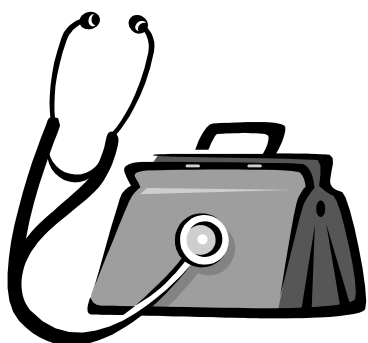
In general, particulate matter is the major pollutant of concern from wildfire smoke. Particulate is a general term for a mixture of solid particles and liquid droplets found in the air. Particulate from smoke tends to be very small (less than one micron in diameter) and, as a result, is more of a health concern than the coarser particles that typically make up road dust. Particulate matter from wood smoke has a size range near the wavelength of visible light (0.4 – 0.7 micrometers). This makes the particles excellent scatterers of light and, therefore, excellent reducers of visibility.

Carbon monoxide is a colorless, odorless gas, produced as a product of incomplete combustion. It is produced in the largest amounts during the smoldering stages of the fire.

Hazardous air pollutants are present in smoke, but in far less concentrations than particulate and carbon monoxide. The most common are acrolein, benzene and formaldehyde.

Health effects of smoke

The effects of smoke run from irritation of the eyes and respiratory tract to more serious disorders, including asthma, bronchitis, reduced lung function and premature death. Studies have found that fine particulate matter is linked (alone or with other pollutants) with a number of significant respiratory and cardiovascular-related effects, including increased mortality and aggravation of existing respiratory and cardiovascular disease. In addition, airborne particles are respiratory irritants, and laboratory studies show that high concentrations of particulate matter cause persistent cough, phlegm, wheezing and physical discomfort in breathing. Particulate matter can also alter the body's immune system and affect removal of foreign materials from the lung, like pollen and bacteria.



Carbon monoxide enters the bloodstream through the lungs and reduces oxygen delivery to the body's organs and tissues. The health threat from lower levels of CO is most serious for those who suffer from cardiovascular disease. At higher levels, carbon monoxide exposure can cause headaches, dizziness, visual impairment, reduced work capacity, and reduced manual dexterity even in otherwise healthy individuals. At even higher levels (seldom associated solely with a fire), carbon monoxide can be deadly.

People exposed to toxic air pollutants at sufficient concentrations and durations may have an increased chance of getting cancer or experiencing other serious health problems. However, in general, it is believed that the long term risk from toxic air pollutants from forest fire smoke is very low. Some components of smoke, such as many polycyclic aromatic hydrocarbons (PAH) are carcinogenic. Probably the most carcinogenic is benzo-a-pyrene (BaP), which has been demonstrated to increase in toxicity when mixed with carbon particulate. Other components, such as the aldehydes, are acute irritants. Three air toxics are of most concern from wildfires:

1. Acrolein. An aldehyde with a piercing, choking odor. Even at low levels, acrolein can severely irritate the eyes and upper respiratory tract. Symptoms include stinging and tearing eyes, nausea and vomiting.
2. Formaldehyde. Low level exposure can cause irritation of the eyes, nose and throat. Higher levels cause irritation to spread to the lower respiratory tract. Long-term exposure is associated with nasal and nasopharyngeal cancer.
3. Benzene. Benzene causes headaches, dizziness, nausea and breathing difficulties, and is a very potent carcinogen. Benzene causes anemia, liver and kidney damage, and cancer.

Not everyone who is exposed to thick smoke will have health problems. Level, extent and duration of exposure, age, individual susceptibility and other factors play a significant role in determining whether or not someone will experience smoke-related health problems.

Sensitive populations

Most healthy adults will recover quickly from smoke exposures and will not suffer long-term consequences. However, certain sensitive populations may experience more severe acute and chronic symptoms from smoke exposure. Much of the information about how particulate effects these groups has come from studies done on urban particulate. More research is needed (and some of it is underway) to determine if particulate from wildfires affects these groups differently.

Individuals with asthma, and other respiratory diseases. Levels of pollutants which may not interfere with normal breathing affect people with asthma in more profound ways, causing greater inflammation or constriction of airways. Asthma, derived from the ancient Greek word for panting, is a chronic condition in which the airways temporarily become impeded, causing labored breathing, wheezing or coughing. During an asthma attack, the muscles tighten around the airways, constricting the free exchange of air. The lining of the airways becomes inflamed and swollen. Children's airways are narrower than those of adults, thus irritation that would produce only a slight response in an adult can result in significant obstruction in the airways of a young child. Older people with asthma experience higher mortality rates from asthma than other age groups.

Individuals with cardiovascular disease. Cardiovascular diseases include many ailments, such as hardening of the arteries, high blood pressure, angina pectoris, heart attacks and strokes. It is the leading cause of death in the United States, responsible for about 42% of all deaths each year. The vast majority of those deaths are in people over the age of 65. Studies have linked particulate pollution to increased heart attacks and symptoms in those with cardiovascular disease. The exact toxicological mechanisms are not well understood, but studies show that particulate matter causes respiratory symptoms, changes in lung function, alteration of mucociliary clearance and pulmonary inflammation that can lead to increased permeability of the lungs. This, in turn, can cause fluid to accumulate in the lungs. Mediators released during an inflammatory response could increase the risk of blood clot formation and strokes. Other studies have shown that the particles may trigger certain neurons in the respiratory tract, leading to effects on the nervous system.

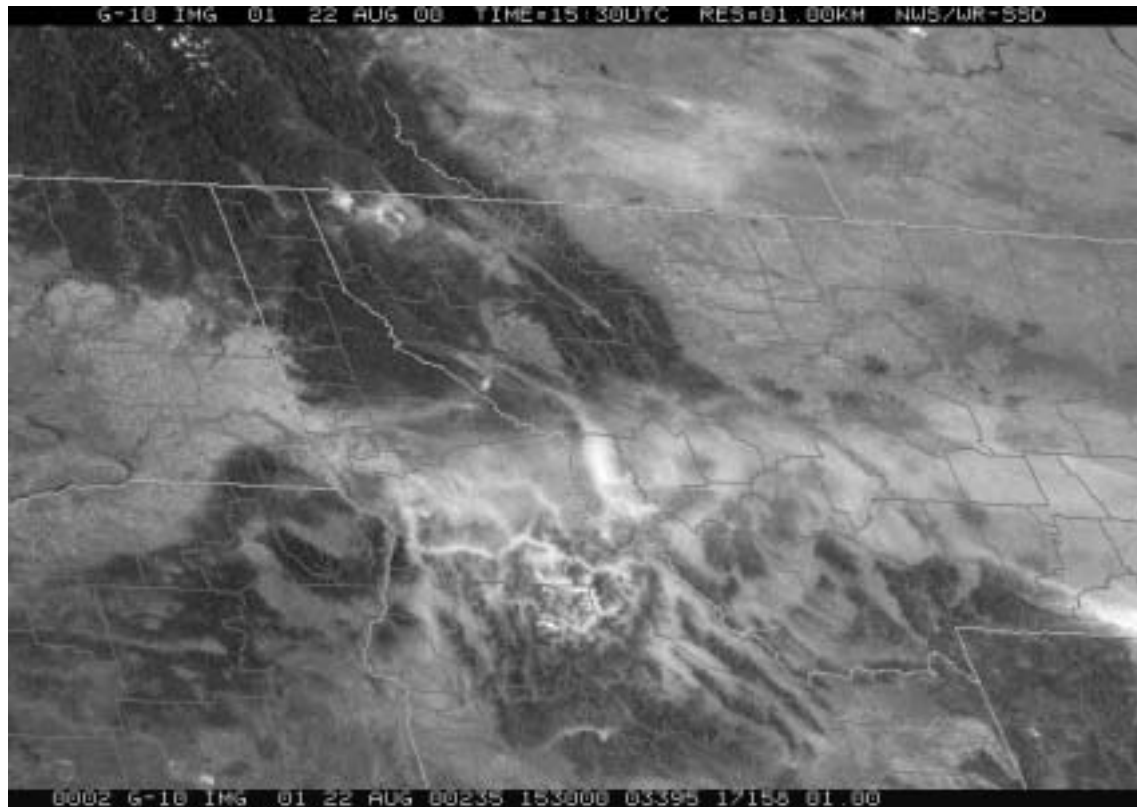
The elderly. Studies estimate that tens of thousands of elderly people die prematurely each year from exposure to particulate pollution. Part of that is due to the fact that the elderly are more likely to have pre-existing lung and heart diseases. In addition, the elderly seem to be more affected than other age groups because we lose important respiratory defense mechanisms as we age. Older individuals tend to have more difficulty clearing particles from their lungs. As a result, pollutants irritate the lungs for longer periods of time and can cause more damage. In addition, particulate pollution can compromise the immune system, increasing the susceptibility to bacterial or viral respiratory infections. This can lead to an increase incidence of pneumonia and other complications among the elderly.

Children. Children, even those without any preexisting conditions, are considered a sensitive population because their lungs are still developing, making them more susceptible to environmental threats than healthy adults. Several factors lead to increased exposure in children: compared to adults, they tend to spend more time outside; they engage in about three times the vigorous activity, and they breathe about 50% more air per pound of body weight. Studies have shown that particulate pollution is associated with increased respiratory symptoms and decreased lung function in children, including symptoms such as aggravated coughing and difficulty or pain in breathing. These can result in school absences and limitation in normal childhood activities.

Smokers. People who smoke have already compromised their lung function. Exposure to high levels of particulate can exacerbate their condition, leading to chest pain, trouble breathing and other respiratory symptoms more quickly than in non-smokers. As a way to put smoking in context, in a 10' by 13' room with an 8' ceiling, it takes only 10 minutes for the side stream smoke of 4 cigarettes to create ambient levels of particulate in the hazardous ranges ($644 \mu\text{g}/\text{m}^3$).

Characteristics of smoke

The behavior of smoke depends on many factors, including the fire's size, the fire's location, the topography of the area and the weather. In mountainous terrain, where inversions are common, smoke often fills the valleys, where, incidentally, people usually live. Smoke levels can be very hard to predict: a wind that usually clears out a valley, may simply blow more smoke in, or may fan the fires causing a worse episode the next day. Smoke concentrations tend to change constantly. (By the time you issue a warning, the smoke may have cleared out.) National Weather Service satellite photos, weather and wind forecasts, and knowledge of the area can all help in predicting how much smoke will come into an area, but predictions are rarely accurate for more than a few hours out. The National Weather Service's website has a lot of information, including satellite photos that are updated throughout the day. For the western United States, the web address is www.wrh.noaa.gov.



Judging particulate levels in smoke

Communities that have established air quality programs and alert systems traditionally base their advisements to the public on the 24 or 8 hour averages of particulate. However, it makes sense to approach smoke emergencies differently, for a couple of reasons. Smoke concentrations tend to be very high for a few hours, and then drop off dramatically. But, research has shown that the spikes may be what cause some of the most deleterious effects. In addition, the particulate from smoke is very small, and has more of an impact than PM₁₀, which is what most emergency plans are based upon. Another factor is public perception. Since smoke is such a good scatterer of light, visibility changes drastically as smoke concentrations increase. Even without being told, the public can tell when the smoke is getting worse, and they want authorities to respond to those changes as they are happening, instead of when they have been going on for eight hours, or when they are over.

Many places don't have real-time particulate monitors to help determine how thick the smoke is. (Real time monitors give an instant (and continuous) reading of particulate concentrations.) However, visibility can serve as a good surrogate. Even in areas with monitors, this index is useful, since smoke levels are ever-changing, giving the public a way to judge the smoke levels for themselves on a continual basis.

Categories	Visibility in Miles	Particulate levels (averaged 1 hour, $\mu\text{g}/\text{m}^3$)
Good	10 miles and up	0 - 40
Moderate	6 to 9	41 - 80
Unhealthy for Sensitive Groups	3 to 5	81 - 175
Unhealthy	1 1/2 to 2 1/2	176 - 300
Very Unhealthy	1 to 1 1/4	301 - 500
Hazardous	3/4 mile or less	over 500

Procedure for Making Personal Observation to Determine Smoke Concentrations

- Face away from the sun
- Determine the limit of your visibility range by looking for targets at known distances (miles). Visible range is that point at which even the high contrast objects totally disappear
- After determining visibility in miles, use the chart to determine health effect and appropriate cautionary statement.

At times, even the visibility index may be hard to use, especially if specific landmarks of known distance are not available for judging distances. In such cases, individuals may have to rely on common sense in assessing smoke conditions (e.g., mild, moderate, heavy smoke) and the kinds of protective actions that might be necessary.

Recommendations for the public

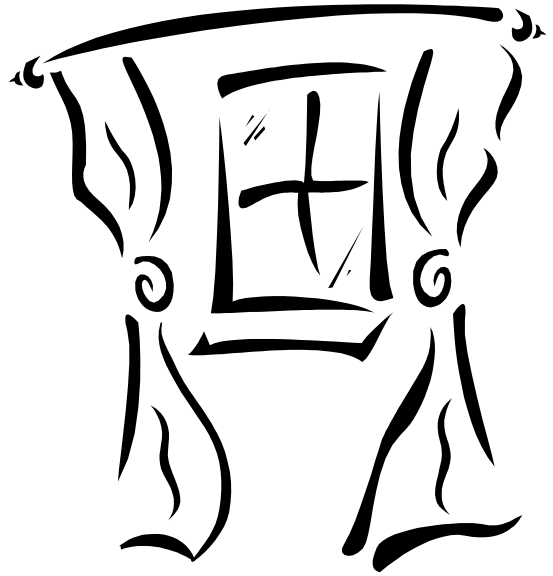
The following table provides a general list of probable health effects at each level, and associated recommended cautionary statements. It is based on the EPA's Air Pollution Index, as well as some work done in Montana and Washington.

Categories	Health Effect	Cautionary Statement
Good	None	None
Moderate	Possibility of aggravation of heart or respiratory disease.	People with heart or lung disease should pay attention to symptoms.
Unhealthy for Sensitive Groups	Increasing likelihood of respiratory symptoms and aggravation of lung disease such as asthma.	People with respiratory or heart disease, the elderly and children should <i>limit</i> prolonged exertion and stay indoors when possible.
Unhealthy	Increased respiratory symptoms and aggravation of lung and heart diseases; possible respiratory effects to general population.	People with respiratory or heart disease, the elderly and children should <i>avoid</i> prolonged exertion and stay indoors when possible; everyone else should <i>limit</i> prolonged exertion.
Very Unhealthy	Significant increase in respiratory symptoms and aggravation of existing lung and heart disease; increasing likelihood of respiratory effects of general population.	People with respiratory or heart disease, the elderly and children should <i>avoid</i> any outdoor activity; everyone else should <i>avoid</i> any outdoor exertion.
Hazardous	Serious aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; serious risk of respiratory effects in general population.	Everyone should <i>avoid</i> any indoor and outdoor exertion; everyone should remain indoors whenever possible.

Specific strategies

Staying Indoors

The most common advisory issued during a smoke pollution episode is to stay indoors. The usefulness of this strategy depends entirely on how clean the indoor air is. Studies (almost none of which were conducted during forest fire smoke episodes) indicate that this strategy can usually provide some protection, especially in a tightly closed, air conditioned house. Staying inside can usually reduce ambient air pollution by about a third. In non-air conditioned homes anywhere from 70 to 100% of fine particulate will penetrate indoors from the outside air. In very leaky homes and buildings, the guidance of staying inside with doors and windows closed may offer little protection. Certainly, if doors and windows are left open, indoor and outdoor air will be about the same.



One of the biggest problems with advising people to stay inside during smoke events is the risk of heat stress. The fire season is often accompanied by high outside temperatures and for those people who depend upon open windows and doors for ventilation, keeping windows and doors closed can be a problem. Older individuals and others in frail health run the risk of heat exhaustion or heat stroke which could have dire consequences. If outside temperatures are very high, it would be prudent to advise those without air conditioning to seek shelter in a clean air sanctuary. These are discussed later in this guide.

Smoke events can last several weeks or months. These longer events are usually punctuated by times with relatively clean air. When air quality improves, even temporarily, residents should “air out” their homes to reduce indoor air pollution.

Air conditioners

Little is known about the impact of using various types of air conditioners and air filters on indoor air pollutant concentrations. The conventional wisdom is that air conditioners reduce the amount of outside particulate to get indoors, if for no other reason than air conditioned homes usually have lower air exchange rates than homes that use open windows for ventilation. Some air conditioners can be fitted with HEPA filters (stands for High Efficiency Particulate) These filters can capture most of the tiny particles associated with smoke and can further reduce the amount of outside air pollution that gets indoors.

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Specific strategies

Air cleaners

Air cleaners can be effective at reducing indoor particulate levels, provided the specific cleaner is adequately matched to the indoor environment in which it is placed. However, they tend to be expensive. Air cleaners can be either a portable unit to clean a single room (\$50 - \$300) or a larger central air cleaner to clean the whole house (\$300 - \$1000+). Most air cleaners are not effective at removing gases and odors. The two basic types of air cleaners for particle removal are:

- (a) Mechanical cleaners, which contain a fiber or fabric filter. The filters need to be sealed tightly in their holders, and cleaned or replaced regularly.
- (b) Electronic air cleaners, such as electrostatic precipitators (ESP) and ionizers. ESPs use a small electrical charge to collect particles from air pulled through the device. Ionizers, or negative ion generators, cause particles to stick to materials (such as carpet and walls) near the device. Electronic air cleaners usually produce small amounts of ozone as a byproduct.

The effectiveness of an air cleaner is usually reported in terms of efficiency, which can be misleading, as it only tells half of the story. The other important factor is air flow. Together, these two factors equal the Clean Air Delivery Rate (CADR), which is a better measure of how a device will actually perform. For example, 99.99% efficiency sounds great, if the flow is only 20 cfm, one would be better off at 90% efficiency and 100 cfm (CADR: 20 vs 90 cfm).

Room units should be sized to supply at least two or three times the room volume per hour. Most portable units will state on the package the unit's air flow rate, the size room it cleans and perhaps its particle removal efficiency and its CADR. Central system air units should handle at least 0.5 air changes per hour, the air exchange rate necessary to reasonably ventilate a house continuously under most conditions.

For central air conditioning systems, electrostatic precipitators, high efficiency media filters and medium-efficiency media filters can be added so that the particle level in the indoor air can be kept within acceptable levels during a prolonged smoke event. However, these filters create more air resistance in the system, and may not be able to be used without modifications to the system.

Devices that remove gases and odors are relatively costly, both to purchase and maintain. They force air through materials such as activated charcoal or alumina coated with potassium permanganate. However, the filtering medium can become quickly overloaded and may need to be replaced often.

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Specific strategies

Some devices, known as ozone generators, personal ozone devices, “energized oxygen” generators, and “pure air” generators, are sold as air cleaners, but they probably do more harm than good. These devices intentionally produce ozone gas to react with pollutants in the air. Ozone is composed of three atoms of oxygen. The third atom can detach from the molecule and reattach to molecules of other substances, thereby altering their chemical composition. It is this ability to react with other substances that forms the basis of manufacturer’s claims. However, the EPA has found that ozone is generally ineffective in controlling indoor air pollution at concentrations that do not greatly exceed public health standards. In addition, ozone does not remove particles from the air, so would not be effective during smoke events. (Some ozone generators include an ion generator to remove particles, but it would be far safer to buy the ionizer by itself.)

Ozone, whether in its pure form or mixed with other chemicals, can be harmful to health. When inhaled, ozone can damage the lungs. Relatively low amounts of ozone can cause chest pain, coughing, shortness of breath and throat irritation. It may also worsen chronic respiratory diseases such as asthma, as well as compromise the body’s ability to fight respiratory infections. As a result, using an ozone generator during a smoke event may actually increase the adverse health effects from the smoke. For more information about ozone generators that are sold as air cleaners, see www.epa.gov/iaq/pubs/ozonegen.html.

Humidifiers are not technically air cleaners, and will not significantly reduce the amount of particulate in the air during a smoke event. Neither will they removed gases like carbon monoxide. However, humidifiers and dehumidifiers (depending on the environment) may slightly reduce pollutants through condensation, absorption and other mechanisms. The greater benefit of running a humidifier in an arid environment during a smoke event would be to reduce stress on the respiratory system, by keeping the mucus membranes moist.

For more information about residential air cleaners, see www.epa.gov/iaq/pubs/residair.html.



Specific strategies

In vehicles

Individuals can reduce the amount of particulate in their vehicles by keeping the windows closed. However, cars heat up very quickly in warm weather, and heat stress can be an issue. Children and pets should never be left in a vehicle with the windows closed. The car's ventilation systems typically removes a portion of the particulate coming in from outside. For best results, most cars have the ability to recirculate the inside air, which will help keep the particulate levels lower.

Reduced activity



Reduction of physical activity reduces the dose of inhaled air pollutants, and may reduce the risk of health impacts during a smoke event. During exercise, people may increase their air intake as much as ten times their resting level. An endurance athlete can process as much as twenty times the normal intake. This brings more pollution deep into the lungs. While exercising, people tend to breathe through their mouths, bypassing the natural filtering ability of the nasal passages: again, delivering more pollution to the lungs. They also tend to breathe more deeply, causing the particulate to lodge deeper into the lungs where it can cause more damage.

Other sources of air pollution

Many indoor sources of air pollution can emit large amounts of the same pollutants present in forest fire smoke. Indoor sources such as cigarette smoke, gas, propane and woodburning stoves and furnaces, and activities such as cooking, burning candles and incense, and vacuuming can greatly increase the particulate levels in a home. Some of these sources can also increase the levels of polycyclic aromatic hydrocarbons (PAHs), carbon monoxide and nitrogen oxides. Besides cigarette smoke, combustion sources that do not vent to the outdoors contribute most to indoor pollutant levels and are of greatest concern. On average, reducing indoor air emissions as much as possible during smoke events may reduce indoor particulate levels by one quarter to one third or more,



and levels of PAHs, VOCs and other pollutants by an even greater amount. These reductions can help compensate for the increased loading from the outdoor air.

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Specific strategies

Masks

In order for a mask to provide protection during a smoke event, it must be able to filter very small particles (around 0.3 to 0.1 microns) and it must fit, providing an airtight seal around the wearer's face. Commonly available paper dust masks, which are designed to filter out larger particles such as dust created by sanding, typically offer little protection. The same is true for bandanas (wet or dry) and tissues held over the mouth and nose. In fact, they may actually be detrimental, giving the wearers a false sense of security and encouraging them to increase their physical activity and time outdoors.

Surgical masks that trap smaller particles are also available, but these masks are designed to filter air coming out of the wearer's mouth, and do not provide a good seal. As a result, these tend to be no better than dust masks.

Some masks (technically called respirators, but they look more like paper masks) are good enough to filter out 95% of the particulate that is 0.3 microns and larger. Smoke particulate averages about 0.3 microns, so these masks will filter out a significant portion of the smoke if they are properly fit to the wearer's face. These masks, which may include an exhale valve, do not require cartridge filters. They are marked with one of the following: "R95", "N95" or "P95." Soft masks with higher ratings (R, N or P 99 and R,N, or P100) are also available and will filter out even more particulate.

Respirators with purple HEPA (pronounced hee-pa and stands for high efficiency particulate air) filters offer the highest protection, but may be less comfortable and slightly more expensive than the flexible masks. Again, unless there is an airtight seal over the wearers face, it will provide little protection.

There are several drawbacks to recommending widespread mask use in an area affected by wildfire smoke. Most people won't use the masks correctly and won't understand the importance of having an airtight seal. For instance, it is impossible to get a good seal on individuals with beards. In addition, masks aren't designed for use by the general population (including children.) As a result, the masks will provide little if any protection. In addition, they may give the wearers a false sense of protection, leading them to ignore other recommendations, like reducing physical activity, which could actually increase their exposure.

Masks are uncomfortable (they are less uncomfortable when they are leaky – but then they do not provide protection.) They increase resistance to air flow. This makes breathing more difficult and leads to physiological stresses, such as increased respiratory and heart rates. Masks can also contribute to heat stress. Because of this, mask use by those with cardiopulmonary and respiratory diseases can be dangerous, and should only be done under a doctor's supervision. Even healthy adults may find that the increased effort required for breathing makes it uncomfortable to wear a mask for more than short periods of time. Breathing resistance increases with respirator efficiency. Most healthy adults can use a 95% efficient respirator without undue breathing resistance. At higher efficiencies, breathing resistance will increase and the user will experience more discomfort.

Another problem with masks is that most of them will not reduce CO.

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Specific strategies

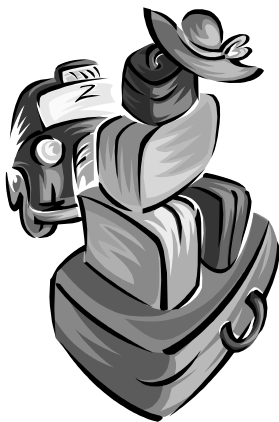
There are some instances where recommending mask use can be beneficial. For outdoor workers, or others that will be outside regardless of the smoke, masks (as long as they fit properly) can afford some protection. In cases where people are generally staying indoors, wearing a mask to go outside briefly might be useful. Masks can also be useful in conjunction with other methods of exposure reduction like staying indoors, reducing activity and using HEPA air cleaners, to reduce overall smoke exposure.

Clean Air Shelters

In many places, staying inside may not adequately protect susceptible individuals. Many homes do not have air conditioning, and depend on open windows and doors for cooling. Other homes may be so leaky, that the pollution levels will soon equal that of outside air. During severe smoke events, clean air shelters can be designated to provide residents with a place to get out of the smoke. These can be located in large commercial buildings, educational facilities, shopping malls or anyplace with effective air conditioning and particle filtration.

Closures

The decision to close or curtail business activities will depend upon predicted smoke levels, environmental and socioeconomic factors and other local conditions. It could be that exposure inside schools and businesses may be similar to or better than those in homes. Children's physical activity may also be better controlled in schools than in homes, making school closings a poor choice. In many areas it will not be practical to close businesses and schools, but partial closures may be beneficial. Closures and cancellations can target specific groups (like the sensitive populations) or specific, high risk activities, like outdoor sporting events and practices. Curtailing outside activities can reduce exposures by encouraging people to stay inside and reduce physical activity. The decision to restrict industrial emissions should be based on the local air pollution situation and the emission characteristics of particular industries. Curtailment may not be beneficial if eliminating industrial emissions will not noticeably reduce the air pollution load.



Evacuation

The most common call for evacuation during a wildfire is due to the direct threat of the fire instead of smoke. Leaving the area of thick smoke may be a good protective measure for members of sensitive groups, but it is often difficult to predict the duration, intensity and

direction of smoke, making this an unattractive option to many people. For fires that go on for weeks, evacuation may not be possible for a large percentage of the population.

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Resources

Montana Department of Environmental Quality: www.deq.state.mt.us/FireUpdates/index.asp

EPA/University of Washington Fire, Smoke and Health Website: www.firesmokehealth.org

National Fire Weather: www.boi.noaa.gov/firewx.htm

National Weather Service: www.wrh.noaa.gov

National Wildland Fire Information: www.nifc.gov/information.html

Forest Service Wildland Fire Morning Report: www.fs.fed.us/news/fire/mornrpt.html

Current Map of Large Fires: wildfire.usgs.gov/website/fireinfo

Satellite Images of Fires: www.osei.noaa.gov/Events/Fires

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This document is a work-in-progress. Comments and suggestions are welcome.